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Simultaneous signalling in digital sound circuits:
a feasibility study

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

SIMULTANEOUS SIGNALLING IN DIGITAL SOUND CIRCUITS: A FEASIBILITY STUDY

Research Department Report No. **1971/26**

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(EL-52)

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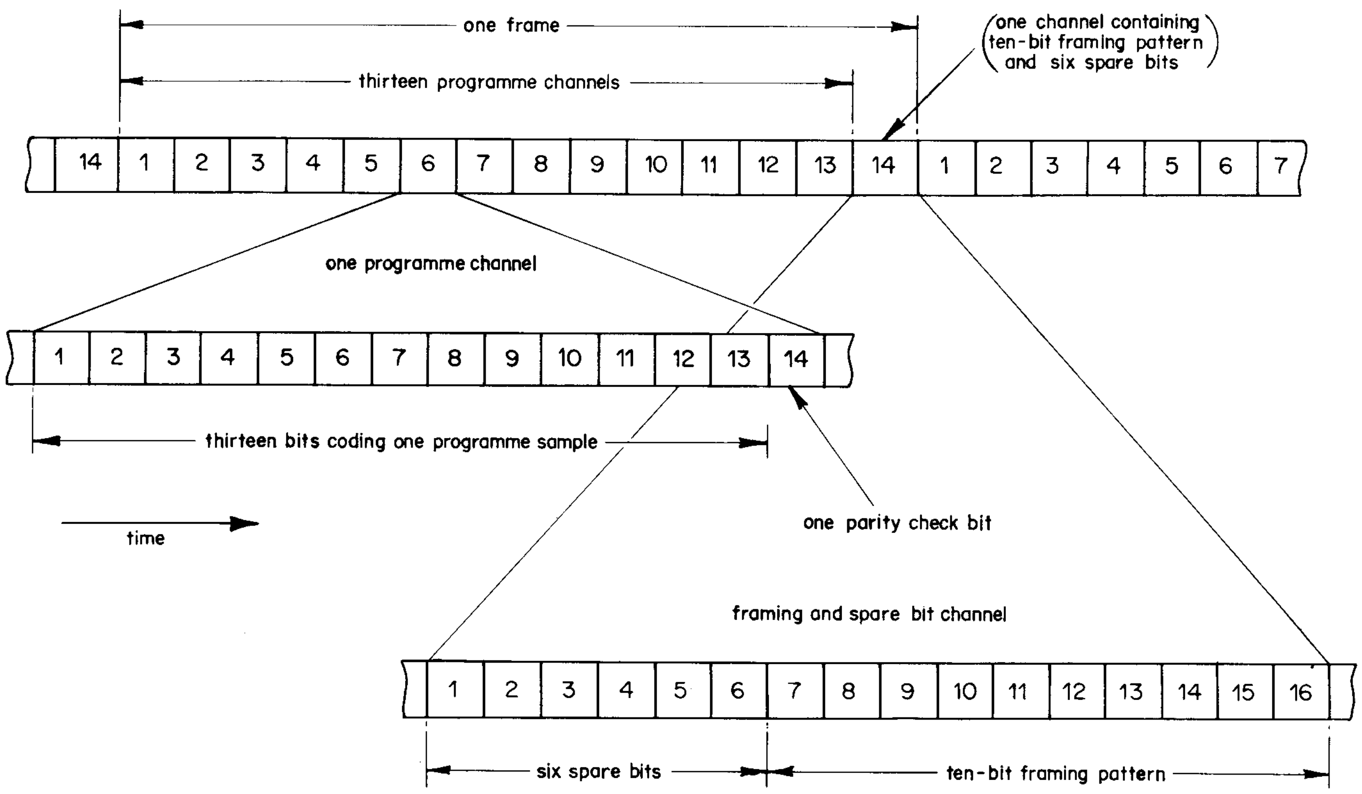
one frame
thirteen programme channels
(one channel containing ten-bit framing pattern and six spare bits)
14
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1
2
3
4
5
6
7
one programme channel
1
2
3
4
5
6
7
8
9
10
11
12
13
14
thirteen bits coding one programme sample
one parity check bit
time
framing and spare bit channel
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
six spare bits
ten-bit framing pattern

Fig. 1 - Format of a multiplex signal conveying 13 sound programmes

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SIMULTANEOUS SIGNALLING IN DIGITAL SOUND CIRCUITS: A FEASIBILITY STUDY

Summary

A number of methods have been investigated by which data for operational control of a broadcasting network may be conveyed as part of a digital time-division multiplex sound-distribution signal. One method utilises bits in the multiplex format which are otherwise unused; the remainder take advantage of redundancy in the sound signals, in the error-checking signals or in the synchronizing signals, to convey additional data without correspondingly increasing the bit rate.

Of these latter methods, two, based respectively on violation of the framing pattern and on occasional substitution of data bits for the least significant bits of the programme signal, offer data rates which are generous for operational control applications and can be applied with simple instrumentation.

1. Introduction

In a recent report[1] various methods of including signals for operational control of the broadcasting network as subliminal additions to an analogue sound-signal were considered. This technique avoids the need to rent special circuits to convey these control signals, thus reducing the complexity of the network as well as saving line rentals.

Control signals will continue to be necessary partners of audio signals when digital transmission is used for sound signal distribution. The exact usage of these control signals has not yet been worked out but it is reasonable to predict that some control signals will be associated with particular programmes and others with particular programme channels, while the rest will need to be separately addressed and may require a time slot in the multiplex 'frame'* that is not used for audio signals.

Three types of control data signals can thus be anticipated:

(i) Data signals which are independent of particular channels.

(ii) Data signals which are tied to a given programme signal.

(iii) Data signals which are tied to a given channel of a multiplex.

Category (i) signals may be associated with the 'housekeeping' time slots that occur once per frame and do not provide audio channels, whilst data signals in categories (ii) and (iii) should be linked to particular programme signals and audio channels respectively.

Economy in the use of bits in a digital system is as important as bandwidth economy in analogue systems. Thus the methods considered in this report are aimed at exploiting redundancy in bits which are provided primarily for purposes other than control signals.

By way of example, the effects of simultaneous signalling will be considered as they would apply to a sound distribution network with a sampling rate of 32 kHz, in which 13 sound programme channels, each with a resolution of 13 bits per channel, are multiplexed on a link carrying $6{\cdot}336 \times 10^6$ bits per second; the format of the multiplex frame is illustrated in Fig. 1. A multiplex system of this kind is under consideration for operational use within the next few years and while the signalling methods to be discussed can also be applied to other multiplex formats the example has the merit of being a likely case.

2. Methods of transmission

Multiplex digital sound distribution offers opportunities to transmit additional data either channel by channel or frame by frame. In digital transmission the 'programme' bits are necessarily accompanied by auxiliary bits for framing and error-checking purposes[2] and sometimes also by unused or 'spare' bits, the presence of which may be dictated by the format of the multiplexing arrangements in use. In digital transmission, therefore, there is a possibility that operational signals may be substituted for framing or error-checking bits in ways which do not significantly affect the system performance. Alternatively, operational data might be judiciously substituted for part of the digital sound signals in such a measure as will produce no audible effect. Arrangements must be made however to mark the start and finish of the digital 'words' of which the data is composed and an allowance of bit rate provided for this 'sub-framing' operation.

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*For further explanation of this and other terms used in describing digital multiplex systems, reference may be made to Research Report No. EL-10, Serial No. 1967/50.

The sub-sections below describe techniques for purloining bits to transmit operational data. The total number of bits per second afforded by each technique is given.

2.1. Use of spare bits occurring in the frame

Spare bits in the multiplex frame may be used freely for the transmission of additional data as they cannot have any adverse effect on the main system performance. Data transmitted frame by frame in this way would not be associated with any particular programme and would need to include an address.

In the example of Fig. 1, six spare bits occur in each multiplex frame and provide a data rate of $1{\cdot}92 \times 10^5$ bits. sec^{-1} of which a small proportion, say 5%, would be required for sub-framing. The net data rate could then be approximately $1{\cdot}83 \times 10^5$ bits. sec^{-1}.

2.2. Transmission by framing pattern violation

In a digital multiplex system it is common practice to use a fixed framing pattern which is transmitted at the sampling rate after the samples from the active channels have each been transmitted once. In high-quality sound distribution the sampling rate is of the order of 32 kHz and the period of the frame consequently about 30 μs. The re-framing time, i.e. the time taken to restore synchronisation after an interruption, is in practice one to two times the interval between successive framing patterns. For the 13-channel system under consideration this is more than adequately short, and simultaneous signalling can be carried out by commandeering the framing pattern time slot on some proportion of its appearances; (since the additional data at the receiving terminal is then identified by violation of the framing pattern, it follows that the framing pattern itself must be excluded from the allowable data words). Any framing patterns which had been spoiled by one or more digit errors on the link would be presented as bursts of erroneous data, and being unrelated to true data they could not be reliably identified by parity checks. In the absence of special measures, the data would suffer a burst error rate n times as great as the distributed error rate on the transmission link, where n is the number of bits in the framing pattern. One method by which the burst error rate in the data could be reduced to be no more than the distributed error rate of the link is to arrange for one bit in the data time slot to be complemented relative to its normal sense in the framing pattern whenever data is sent. Using the inversion of this bit as an additional criterion for the acceptance of data would eliminate spurious data cuased by framing patterns in which other bits had been spoiled.

In the multiplex system referred to in Section 1, the effect on re-framing time can be shown to be quite negligible if only one framing pattern time slot in ten is taken over for data transmission; the data which could be sent by framing pattern violation could therefore certainly equal 1 word per 10 framing pattern time slots. In the example of Fig. 1 this would be 3200 words per second and if one of the 10 bits in the word slot were used to perform the check as described above this would give a data rate of 9 x 3200 bits. sec^{-1}.

The maximum data rate possible with this system of transmission could not be established in the present study because it depends on the details of the particular re-framing method employed, and time did not permit an exhaustive investigation. A test was however performed, using an experimental multiplex system having a 38 kHz sampling rate and a 14-bit framing pattern; the pattern was deliberately spoiled in every alternate frame to simulate the substitution of additional data. Although the average re-framing time must have been doubled, the additional delay in the acquisition of programme could not be heard. The transmitted data rate simulated in this experiment was:

$$\frac{(14-1)\,(3{\cdot}8 \times 10^4)}{2} = 2{\cdot}47 \times 10^5 \text{ bits. sec.}^{-1}$$

Although the above experiment did not embrace the performance of the system under adverse transmission conditions, it raises the question whether the transmission of a framing pattern at the sampling rate, convenient though it may be instrumentally, implies extravagent use of part of the transmission capacity of the system which should be otherwise employed.

2.3. Use of least significant bits

The methods of Sections 2.1 and 2.2 were suitable for additional data transmitted frame by frame. The remaining methods to be discussed concern data injected into individual programme channels or into programme signals, i.e. category (ii) or (iii). Such data may be transmitted by occasional appropriation of the least significant bit (l.s.b.) of a programme sample code, the occasions being so widely separated that the errors thus introduced into the programme signal are inaudible. The data may most simply be transmitted at regular intervals controlled by a counter, or, with more complication, at intervals chosen according to pseudo-random sequence under the control of a suitable generator.

2.3.1. Injection at constant rate

Listening tests were carried out using the 13-channel system referred to earlier; in this system, interpolating waveforms are added to the analogue signal before coding to reduce distortion at low signal levels.[3] In order to simulate data of a form producing the worst subjective impairment the l.s.b. of the digital programme signal in one channel was replaced at regular intervals with a '0'. This resulted in the generation of a buzzing sound, of fundamental frequency equal to the data injection rate, which, though masked by quantising noise whenever programme was being transmitted, could sometimes be heard when the channel was idling. The buzz was audible only when the rate of injection lay above about 1000 per second. The gross bit rate available for data transmission is therefore up to about 1000 bits. sec^{-1} per channel, from which a small proportion might require to be deducted to provide synchronisation and sub-framing for the extraction and decoding of the data.

2.3.2. Injection at pseudo-random intervals

If transmission of data is accomplished by taking over the least significant programme bit in time slots

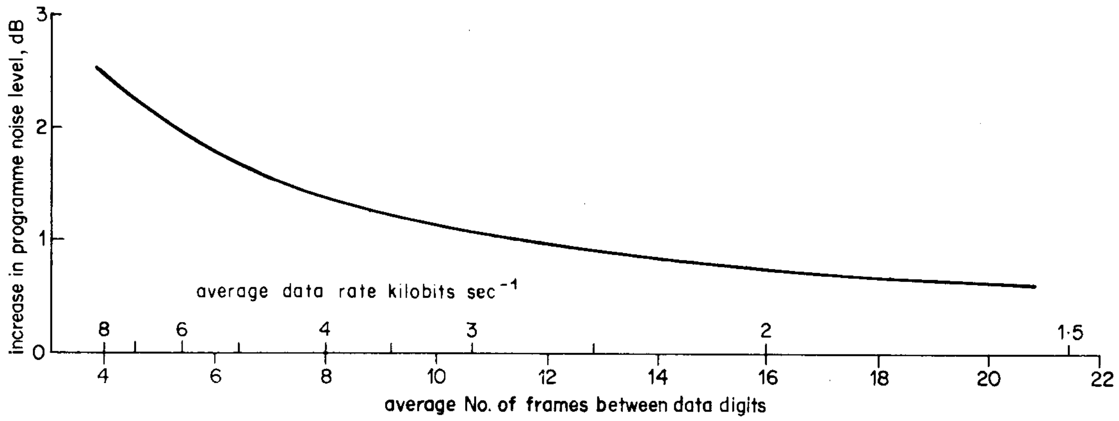

Fig. 2 - Insertion of data in place of the least significant bit of a sound signal at pseudo-random intervals

selected by a pseudo-random sequence generator the only effect on the sound programme should be an increase in the noise level to some value above that produced by quantising; this conclusion was confirmed by a listening test. Fig. 2 shows the calculated increase in noise level with the average bit rate of the additional data transmitted. For an increase of 1 dB in noise level, data can be transmitted at a rate of 2 500 bits. sec^{-1} in each channel. As with transmission at a constant rate, a small proportion of the data capacity will be required for synchronisation and sub-framing. A very simple way in which this could be done is to set the receiving counter or pseudo-random generator to zero at intervals by means of some recognizable pattern transmitted for this purpose, using the least significant bits of all the programme channels.

2.3.3. Injection by linking to specific sound-signal code

Data could be transmitted by replacing the least significant bit by data only when the other bits of the coded sound sample form a pre-selected pattern. The instrumentation required would be simple, but the maximum possible bit rate would be very low. For 13-bit coding with 32 kHz sampling rate, assuming that all possible digital programme signals are equiprobable, the data transmission rate can be shown to be only 4 bits/second. Moreover, with this system data cannot be sent during intervals when the coder is idling unless the coder is specially designed for the purpose; this is an important consideration since most control switching activity occurs at this time. Because of this disadvantage and the low data rate obtainable, this method of transmission was pursued no further.

2.4. Transmission of data by violation of channel parity

In a digital sound distribution system provided with a parity checking bit for each channel, data may be transmitted by occasionally generating a wrong parity bit. Parity violation generally results in an error concealment technique being applied in which the erroneous programme-signal sample is discarded and is replaced, for example, by repetition of the previous sample; in these circumstances all the bit positions of the discarded programme-signal become available for data transmission. This liberation of whole block of bits, easily identified by the parity violation and thus requiring no additional framing information, constitutes the major attraction of signalling by this method.

Some impairment in the sound programme is caused by repeating the sample whenever parity violation is detected. Listening tests showed that with the simple system described above, one sample repetition every 3 seconds, i.e. about 4 bits sec^{-1} for each channel for a 13-bit system, was the upper limit of the acceptable signalling rate.

A modification of the method, in which more data can be inserted by choosing propitious moments in the sound signal to reduce the impairment, has been investigated. The propitious moments occur when two successive programme signal samples are very nearly equal; data may then replace the second sample and the first may be repeated with very little subjective disturbance. Near-equality can be detected by comparing the more significant digits of successive coded programme signal samples. A data word to be transmitted is stored until a near-equality occurs. Since occurrences of equality are irregularly distributed depending upon the nature of the sound programme, a suitable opportunity to transmit a particular data word may not occur before the arrival of the next word, a situation which we shall for brevity call 'refusal' of data. Fig. 3 shows the probability of data being refused plotted against the required data word rate, with the number of bits-per-word compared for equality as parameter. The curves are calculated on the assumption that all quantised values of programme sample are equiprobable.

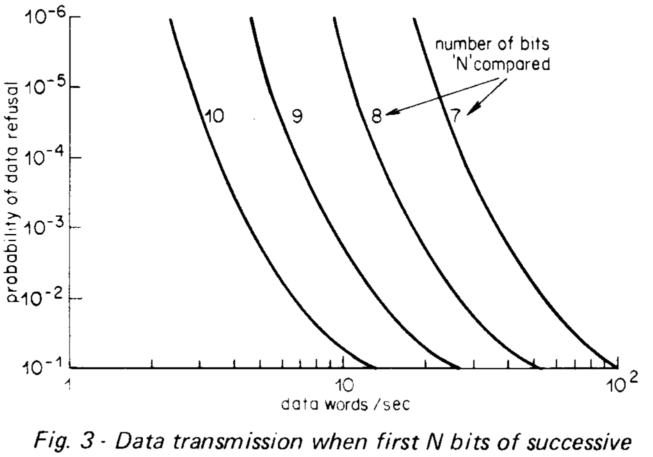

Fig. 3 - Data transmission when first N bits of successive samples are equal: probability of data refusal

The maximum signalling rate for just perceptible impairment of the sound channel was determined by a subjective test. In over 75% of the tests the listeners were unable to detect any impairment for an average rate of data injection of 4 words per second when 10 bits were being compared for sample equality. To avoid impairment of the programme it is therefore sufficient that the average data rate should be restricted to 4 words per second by using only a proportion of the near-equalities signalling by the digit comparator. On those occasions when data is refused, however, equilibrium can be regained by temporarily transmitting data at every near-equality, until the backlog has been dealt with.

A data word rate of 4 per second would, in a 13-bit sound channel, give data bit rate of 52 bits $\sec^{-1}$ per channel.

A further complication arises however when the transmission system is subject to errors. As with the system of data transmission by framing pattern violation described in Section 2.2, transmission errors which violate the parity will result in a group of bits which are really part of the sound signal being presented as data, so producing a burst of errors one word long. If, for example, a multiplex with a 32 kHz sampling rate in which six bits in each channel are included within the parity check, is subject to a distributed bit error rate of 1 in 10^6, parity violations by errors will occur at an average separation of $10^6/(6 \times 32 \times 10^3) = 5$ seconds in each channel. When data is transmitted at 4 words per second one data word in 20 will be false, an unacceptable error rate for most purposes.

In a multiplex system, the difficulty can be overcome by confirming the presence of data by transmitting a pattern using the least significant bits of all the channels. (In a 13-channel multiplex carrying data on each channel at a rate of 4 words $\sec^{-1}$ this action would take place on average $4 \times 13 = 52$ times per second.) Using this artifice, of 32000 words received by each channel per second only 52 will be signalled as possible data by the pattern of least significant bits. The probability of an erroneous word being accepted as data is therefore reduced by $52/(32000) = 1{\cdot}6 \times 10^{-3}$; in the above example, in which the bit error rate was 1 in 10^6, the data word-error rate is then $1{\cdot}6 \times 10^{-3} \times 1/(20) = 8$ in 10^5.

Although the method of signalling by parity violation appeared at the outset to be attractively simple, the instrumental complexity required to select suitable signalling opportunities, to store data before transmission, to change mode when data accumulates, and to confirm the presence of data by a pattern, is such as to remove much of the attraction.

3. Conclusions

Seven methods of simultaneous signalling in digital sound distribution circuits have been examined. Two of them, the use of spare bits, and signalling by framing pattern violation, provide frame-by-frame data. Whilst the former amounts, in effect, to the use of a separate data channel and takes up a corresponding information bandwidth, the latter provides a simple method of transmission using the redundancy of what is basically an over-framed multiplex. The transmission rate possible with framing pattern violation will depend upon the framing method employed, and is sufficiently high with conventional framing techniques to suggest that it could be used to transmit high-speed control data.

Alternatively, further work to devise the most economical framing method, which would just meet the subjective requirements for re-framing, might permit framing at a lower speed to be accomplished, using the bits currently regarded as spare in the multiplex, and possibly provide an additional high quality sound channel within the 6·336 Mbit $\sec^{-1}$ total bit rate.

Of the remaining simultaneous signalling methods examined, all of which carried channel-by-channel data, the use of the least significant bits of the channels at regular intervals appeared simple and effective for channel data rates less than 1000 bits $\sec^{-1}$. The more complex method of injection of data in the l.s.b. using a pseudo-random generator would only be employed if the channel data rate were required to exceed 1000 bits $\sec^{-1}$.

Injection of data in the l.s.b. when a particular sound-signal code is sent provides too low a data rate to be of service and would not permit data transmission in programme pauses.

Transmission by channel parity violation provides a data rate of only about 50 bits $\sec^{-1}$ per channel, and although it requires no word framing, the instrumentation required would be rather expensive.

4. References

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